EDITORIAL

JOSEPH BARRELL AND HIS WORK

Joseph Barrell, a younger contemporary of Dutton, Gilbert, Powell, and Van Hise, to name only the most eminent of those upon whose work he built and whom he survived, is outlived by a number of older geologists who recognized in him a rising leader in research, and who feel his loss deeply, as that of a strong, judicious, yet enthusiastic and sympathetic fellow-worker.

Born in 1869, Barrell entered upon his career at a time when the leading minds in geology were opening up bonanzas of fact and theory. Already notable progress had been made in development work. The early prospecting of the Great West which followed the Civil War had been succeeded by the organization of the United States Geological Survey and the consequent co-ordination of studies carried on by able men under the stimulus of companionship in a great opportunity. That companionship, previously divided among small and often antagonistic groups, became general and cordial in consequence of the founding of the Geological Society of America in 1889. Discussion, concession, and co-ordination replaced controversy and opened the way for permanent constructive effort. Barrell fitted pre-eminently into this environment, which emphasized truth and subordinated self.

His scientific life thus coincided with the golden era of geology in America. The brilliancy of its earlier years inspired his studies, and during the last two decades he himself has contributed notably to its advance. Estimating the relative contributions of enlightened nations to geology, he wrote as recently as March, 1919: "For the past generation America, under which name should be included both the United States and Canada, has held a position of world-leadership in that science." The place which he himself filled in that leadership his contemporaries cannot justly estimate. But there is unanimous recognition of the fact that he was one of the strongest of the younger leaders and a man of great promise.

Lehigh University trained Barrell. He received three degrees, Bachelor (1892), Engineer (1893), and Master (1897), from that institution, took the degree of Doctor of Philosophy at Yale in 1900, and was honored by that of Doctor of Science in 1916 by his Alma Mater. Prior to his studies at Yale he had both taught and practiced mining engineering, and he continued to be an engineer when he became a geologist. His reasoning is stamped with the precise habits of thought which distinguish the practical from the theoretical. It is told that he would often draw a diagram before he wrote a statement.

Barrell pursued geology with ardent scientific interest from 1898 on, and thus gave a score of years of the prime of his life to it. As assistant in field work of the United States Geological Survey (1899–1901) and as a teacher of the natural sciences, especially of zoölogy and geology at Lehigh (1900–1908), he prepared himself for advanced research in its greater problems, and while occupying the chair of structural geology at Yale (1908–19) he found the larger opportunity to develop his especial abilities as an Engineer of Science.

The phrase engineer of science is used with all regard and respect to distinguish Barrell's activities from those of his great associates, who are better known in the field of theoretical investigation. It is a prime function of the engineer to test assembled materials, in this case facts, before proceeding to build with them firm structures, in this case logical conclusions. His work is kept by professional standards within limits which are fixed by quantitative values. Excursions into the realm of theory beyond those limits Barrell allowed himself only in his latest thought. In so doing he gave evidence of a tendency to develop from the engineer into the natural philosopher, whose thought transcends analysis as imagination transcends mathematics. The great loss to science in Barrell's death is that this evolution of mind from so fertile a source was cut short when there was yet promise of a score of years of productive growth.

The engineer in geology is strikingly illustrated in Barrell's first important contribution to the science, an article on the relative importance of continental, littoral, and marine sediments. He set forth his method of studying sedimentary structures and their

origin as comprising, first, discussion of the conditions of formation of sediments; second, comparison of the areal and volumetric importance of the several kinds of deposits now forming; third, consideration of the probable changes in relative importance which may have occurred in the past; and fourth, presentation of detailed distinctions by which the several deposits may be recognized, with a view to separating and interpreting them in terms of geography and climate.

It may be said that this is the sound scientific method of proceeding from facts to interpretation. It is also sound engineering. It builds permanent structures. By means of it, in the paper referred to and by others in which he applied the distinguishing criteria of sedimentation to specific examples, Barrell made an important and essentially original contribution to geology in that he forced the recognition of continental, fluviatile, and eolian sediments among stratified rocks which had been previously regarded as of marine origin exclusively. He thus revolutionized the criteria of paleogeography and paleoclimatology.

Paleoclimatology is a field to which Barrell unlocked the gate, if indeed he may not be said to have discovered it. His article on relations between climate and terrestrial deposits traces the complex variations of temperature and rainfall and their effects upon sediments with such keen analytic power, such wealth of illustration, and such logic as to lay firmly the foundations of interpretation of terrestrial stratigraphy in terms of climate.

Among the great problems of the past thirty years in geology and geodesy there is none more congenial to a mind like Barrell's than that of the strength of the earth's crust. His investigation of the subject illustrates the conscientious thoroughness with which he did his work. He was so serious, so earnest in investigation, that he could not leave any aspect of a subject untouched. His presentation is therefore an exhaustive review, analysis, and critique of the contributions previously made, together with a statement of the deductions which he found reasonable. He attacked the complexities of the subject, not only as a geologist and engineer, but also as a mathematician. He did not hesitate to enter the lists against those who arm themselves with higher mathematics and who seem invulnerable to attack by geologists

unfamiliar with the weaknesses of their armor. In the *Strength of the Earth's Crust* Barrell demonstrated the character and quality of his mind. He was a great analyst.

It is of interest to contrast Barrell's method with Gilbert's in the discussion of the fundamental problems of isostasy. Gilbert was a co-worker with Dutton in the studies that gave birth to the concept. Dutton formulated the idea of isostasy in 1889, and Gilbert discussed the related problem of crustal strength in 1890 in *Lake Bonneville*, the manuscript of which, so far as it touched this subject, was under consideration in 1888 and earlier. Gilbert's last contribution to the subject was in 1913. It is a brief but comprehensive interpretation of anomalies of gravity. In the interval of twenty-five years he wrote but little on isostasy, although he was associated with Putnam in the initial studies of gravity intensities in the United States and followed Hayford's brilliant work with constant interest. He published far less in a quarter of a century of investigation than Barrell has given us in one group of articles. Barrell's analysis covers every part of the subject exhaustively, dissociates all its elements, weighs them, and recombines them. It is the product of extraordinary industry, activity, and thoroughness. Gilbert, a profound thinker, a philosopher, awaited patiently the unfolding of knowledge. He entered into no controversy. Nothing escaped him, but he was content to sketch the edifice of truth in terms of fundamental principles. He anticipated Barrell in conclusions as to the relative importance of rigidity and isostasy, which the latter's exhaustive analysis confirmed.

A work comparable in exhaustive treatment with Barrell's *Strength of the Earth's Crust* is his *Rhythms and Geologic Time.* Rhythms in denudation and rhythms in sedimentation are discussed through sixty pages, emphasis being laid upon the pulsatory character of uplifts and subsidences. In contrast to previous discussions the view is developed that "the deposition of nearly all sediments occurs just below the local base level, represented by wave-base or river-flood level, and is dependent on upward oscillations of base level or downward oscillations of the bottom." If this be so, it follows that there are numerous interruptions in the process of sedimentation, some of which are already known as

disconformities, while to others of lesser duration in general Barrell would apply the term "diastem." The recognition of diastems and disconformities greatly lengthens the estimates of geologic time based on sedimentation. This discussion is followed by a review of all previous estimates of geologic time, distinguishing those based on oceanic salts and on radioactivity. The latter is fully and favorably presented. The paper closes with a section on the convergence of evidence, in which the physical terrestrial phenomena are compared with those of biologic evolution and stellar evolution. The trend of the argument is toward the acceptance of a very great age for the earth, possibly fifteen hundred million years. But, on the other hand, the amount of solar energy due to gravitational infall is found to be but approximately 1 per cent of that which would have been radiated during that immense lapse of time, and Barrell is thus led to consider the probability that there are other sources of energy in the sun than gravitational condensation. He recognizes that the great concentrations of energy must have previously been stored, and concludes: "The scheme of the universe is more profound and the unknown is a little nearer than it was recently thought to be."

The planetesimal hypothesis of the genesis of the planets has taken a permanent place among the foundations of geologic theory in America. Reviewing Chamberlin's *Origin of the Earth* Barrell wrote:

> To gain a proper appreciation of the value of the investigations which are condensed in this volume we must compare the present state of thought upon the general subject with that of twenty years ago, before Chamberlin had begun to publish upon the hypotheses of earth-genesis. Measured by that perspective, this volume is seen to represent an advance in thought on this subject so great that the names of Chamberlin and Moulton must rank high among those scientists who have dealt constructively with that vast, vague, and remote problem, the origin of the earth. The subject of earth-genesis is now fairly on the road to scientific investigation in place of philosophic speculation.[1]

It was characteristic of Barrell that he should translate the thought of the last sentence into action and should proceed to investigate the subject of earth-genesis by applying tests to Chamberlin's hypothesis, or rather to the group of multiple hypotheses, some of which were adopted and some discarded by Chamberlin in

[1] *Science*, 1916.

reaching the final, most reasonable, conclusion, as he saw it. However, in judging alternatives, there are many opportunities for divergence of opinion, and among those which are offered in this particular case Barrell has seized upon the one which is most significant in separating two distinct lines of geologic inference: Did the earth grow up as a comparatively cold, solid globe, or did it become molten and cool down from that condition? The question turns upon the size of the planetesimals and their manner of infall. We may best let Barrell state the alternatives by quoting from a lecture delivered by him at Yale in November, 1916:

> Under the terms of either nebular or planetesimal hypothesis a scattered state of the planetary material is implied as a stage antecedent to the origin of the planets. Was this growth of the planets geologically slow or rapid? Did it take tens or hundreds of millions of years, or was it on the contrary largely accomplished in tens or hundreds of thousands of years? Was the material largely in dust-like or molecular form or was it to a large extent in nuclei of considerable size? From these different postulates very divergent consequences may be traced in the formative stages of the earth; and finally the present nature of the earth itself may speak in favor of one or the other of these views.
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> Chamberlin adopts the hypothesis that the stages of earth-growth were very prolonged, even geologically speaking, and that the accretion was dominantly of dust-like or molecular particles. According to him the building up of the planets followed three stages: first, the direct condensation of the nuclear knots of the spirals into liquid or solid cores; second, the less direct collection of the outer or orbital and satellitesimal matter; third, the still slower gathering up of the planetesimal material scattered over the zone between adjacent planets. This third factor in Chamberlin's view is regarded as very important, and he believes this diffused matter contributed much of the earth's substance, very slowly and in dust-like form. This is one of the critical points in the details of the theory upon which turns much of the development of the following argument.
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> Chamberlin conceives the earth to have been built up as a solid body, not to have been fluid or viscous at any time later than the early nuclear stage, and to have begun to hold an ocean by the time it contained thirty or forty per cent of the present mass. Such liquid rock as was generated by compression or radioactivity during earth-growth is regarded as having been kneaded and squeezed to the surface, where it solidified approximately as fast as it was formed. In earth-growth the denser planetesimal dust, he argues, tended to be somewhat segregated into the primitive ocean basins, and served to maintain in them, as the earth was built outward, a greater density than in the elevated zones between, establishing thus a relation between density and elevation.

It seems a debatable question if such a large proportion of the added material was necessarily dust-like and capable of being weathered, sorted, and distributed by the primitive atmosphere and ocean. . . . . In fact, from this beginning of earth-growth the preponderance of the evidence appears to the writer to be against those sub-hypotheses which Chamberlin has followed. This evidence, its bearings, and conclusions will form the following parts of this article. It will be of ultimate value to both lines of argument that each may be weighed against the other. . . . .

It appears to the writer that the chemical character of the igneous rocks, the limited depth of density variations in the crust, the limited amount of salt in the sea, the rotation period for the moon and planets, all point to a molten condition of the earth at the completion of its growth. . . . . The questions raised by this conclusion are: What mode of growth would have favored the molten state and how far did this precede the beginning of the geologic record as given by the oldest rocks exposed at the surface of the globe ?[1]

Barrell then proceeds to discuss in terms appropriate to a lecture rather than to an analysis, as the occasion demanded, the significance of the planetoids, the indications of primordial tidal retardation, and the deductions which may be drawn from the limited amount of oceanic salt as to the age of the ocean. Condensed though it is, the argument is too long to be quoted here, but the description of the early stages of the earth, as Barrell conceived them, sheds light upon the tendency of his mental development:

The indications of primordial tidal retardation and the limited amount of salts in the sea both point to the conclusion that the earth was molten at the completion of its growth. The molten state suggests a rapid earth-growth due to an original clustering of the matter whose convergence built up the planet. Larger nuclei, hundreds of miles in diameter, and smaller ones comparable to the planetoids, moved in elliptic and nearly intercepting orbits. Mutual perturbations kept modifying these orbits and providing new chances for collisions, union, and growth. Such collisions led to a development of energy of impact sufficient to produce in the growing earth a molten state at least in the outer portions. The earth kept growing at the same time by sweeping up large quantities of finer material, but a molten state suggests that the greater growth was due to the infall of the larger nuclei. Finally but one outstanding nucleus, the moon, was left beside the earth, and the earth-moon system attained a condition of stability and completed growth.

After describing the state of the molten globe, which he conceives to have been surrounded "even in its molten stage by an

[1] The first of a group of lectures delivered before the Yale chapter of Sigma Xi during the academic year 1916–17, entitled "The Evolution of the Earth and Its Inhabitants. The Origin of the Earth," by Joseph Barrell.

envelope of water in the form of a deep and heavy atmosphere of water gas," forming an effective thermal blanket, Barrell continues:

> The effectiveness of the blanket depended upon the peculiarity of both water gas and carbon-dioxide in being opaque to the slow vibrations of dark heat, absorbing these near the bottom of the primitive atmosphere and re-radiating them from higher levels as long, slow heat waves. Strong convection currents carried up these heated gases from the superheated base to the higher levels of the atmosphere. There the chilling condensed the water vapor into a thick and universal canopy of cloud, boiling up like thunder heads from below, shedding continuously a downpour of acid rain, rain dissipated again into vapor as fast as the drops fell into the deeper and hotter strata of the atmosphere. The intensity of the vertical convection maintained a high electric tension. Incessant flashes of lightning linked as with living fiery tentacles the cloudy heavens to the lurid molten earth. Tremendous reverberations of thunder, unsensed by mortal ears, shook the atmosphere in the world-wide primeval storm. . . . .
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> During the more rapid growth-stages the molecular and dust-like matter swept up by the earth settled like a never ceasing cloud of volcanic ash. The planetesimals of sand and gravel size were swept up by the earth many millions of times more abundantly than our meteors at the present time. Those meeting the earth with the higher velocities were consumed by impact. Over the hemisphere of night the otherwise invisible atmosphere above the cloud canopy scintillated with incessant flashes of light and trails of luminous dust. Bodies of larger size gave in their dissolution a still more brilliant display and penetrated to greater depths. At longer intervals, with Titanic rush and roar, a greater projectile, tens or even hundreds of miles in diameter, cleaved through the canopy of cloud, leaving a tumultuous maelstrom behind, drove almost unchecked through the dense atmosphere below, and, with world-wide commotion, was engulfed with development of fervid heat, within the molten sea.

Only he who has a sure grasp on the controls can safely essay a flight of the imagination where the conditions so surpass all experience. Barrell's earlier, intensely analytical work showed little evidence of the power of philosophic speculation, the scientific use of the imagination, which is nevertheless the parent of investigation, even as Chamberlin's thought is the father of Barrell's. Barrell would have fallen short of the full stature of the philosopher if he had not developed beyond the engineer. Such passages as those quoted above show that he had grown in imaginative power, and, being severely controlled by the logical habit of thought of his early engineering and scientific career, he would have used that power judiciously, greatly to the advantage and advancement of

science. His death has robbed us at the moment when his promise was greatest.

Barrell's work is not yet done; his service to science and to his fellow-men is still incomplete. He has left it in our hands and in those of the younger generations to come. His research, which he loved, is to be carried on. His example, which is inspiring, is to be followed. We may well ask, as suggested by Dr. Branner, How are young men to be trained up to become Barrells? His mental qualifications were not extraordinary. His schooling was not unusual. Yet he became a most unusual man.

The reason for Barrell's strength can be expressed in two words, thoroughness and breadth. Whatever Barrell did he did thoroughly. The articles cited in this memoir demonstrate that fact. But let it be borne in mind by any young man who would aspire to be like him that such thoroughness is a habit of slow growth. He who would possess it must begin soon and must determinedly will to be thorough. Barrell studied thoroughly, acquired knowledge thoroughly, so that he knew what he knew, not for today or tomorrow only, but for his lifetime. For that reason he was able also to be broad.

Breadth and thoroughness of knowledge are often considered incompatible, and it is true that thoroughness and specialization are commonly associated. But thoroughness in laying foundations is the basis of great breadth of superstructure. Barrell was thorough in acquiring the elements of mathematics, chemistry, physics, geology, meteorology, astronomy, and zoölogy. He knew well the general principles, the broad facts, the methods of each science. He was firmly founded in them. Thus, when he had occasion to study climates of the past he approached them with an understanding of climates of today. When he would discuss the strength of the earth he could command his mathematics and mechanics. When he undertook to explore the unknown realms of earth-genesis he was equipped with an understanding of astronomy and physics that supplied the seed from which to grow his tree of knowledge. When he gave his imagination flight it was on wings of strength that it soared, giving us confidence that it could soar safely and to great heights, whence the profound depths of the unknown might be searched.

BAILEY WILLIS